

# Canadian Research on Black Carbon and Climate Change

## **Lisa Graham**

Senior Chemist  
Emissions Research and Measurement Division  
Environment Canada

## **Greg Smallwood**

Combustion Technology Group  
Institute for Chemical Process and Environmental Technology  
National Research Council Canada

## **Jeff Brook**

Air Quality Research Branch  
Meteorological Service of Canada  
Environment Canada

# Canadian Context

- 1992: Canada ratifies UNFCCC
- 1995: Federal Action Plan on Climate Change
  - Science of climate change (GHG focus)
  - CO<sub>2</sub> capture, storage and disposal
  - Energy efficiency (CO<sub>2</sub> reductions)
  - Renewable energy
  - Forestry management
- 2002: Canada ratifies Kyoto Protocol of UNFCCC
- 2004: Canada releases GHG Inventory 1990-2002 as part of requirements of Kyoto Protocol.

# Canadian Context

- 2002: Climate Change Plan for Canada
  - Reduce annual CO<sub>2</sub> emissions by 240 MT
    - Transportation
      - Improve new vehicle efficiency by 25% by 2010
      - 10% ethanol gasoline blend in 35% of market
      - Increase biodiesel production to 500 M Litres
      - Improve freight transport efficiency
    - Housing and Commercial/Institutional Buildings
    - Large Industrial Emitters
    - SME's and Fugitive Emissions
    - International Emissions Reductions
    - Canadians, Communities and Governments

# CCT&II

- Climate Change Technology and Innovation Initiative
- R&D component of Climate Change Plan
- \$250M funding through 2003-2008
- Transportation is one of 9 program lead areas
  
- Goal of program is to develop long term solutions to reducing GHG emissions
  - Not the same as reducing anthropogenic contributions to Climate Change

# Black Carbon?

- With all this talk about GHG emissions reduction, where does black carbon fit in?
- Our intent with our research is to inform our policymakers that mitigating climate change is more than just reducing CO<sub>2</sub> emissions.

# CCT&II

- Transportation End Use Efficiency (\$8M over 5 years)
  - 5 Activity Areas in Transportation
    - Vehicle Technologies and Materials
    - Engine and Powertrain Technologies
    - Fuels and Energy Carriers
    - Integrated Transportation Systems
    - Codes, Standards, Policy, Outreach and Education (~\$1.5M over 5 years)
      - Knowledge Base Development (emissions and activity)
      - **Black Carbon and Aerosol Roles in Climate Change**
      - Public Education and Guidance

# Black Carbon Year 1

- Assessment of existing Canadian black carbon data
  - Ambient measurements
  - Source emissions
  - Atmospheric transformation processes

in support of developing proposal for years 2-5.

- Feasibility of using carbon isotopes to identify sources of black carbon
- Feasibility of extending laser-induced incandescence (LII) for ambient black carbon measurements

# New Proposal

...will build upon ongoing research activities in the areas of

- source and ambient measurements
- atmospheric processes studies
- data analysis and modeling
- emissions inventory development
- source apportionment
- measurement methods
  - carbon isotopes and LII

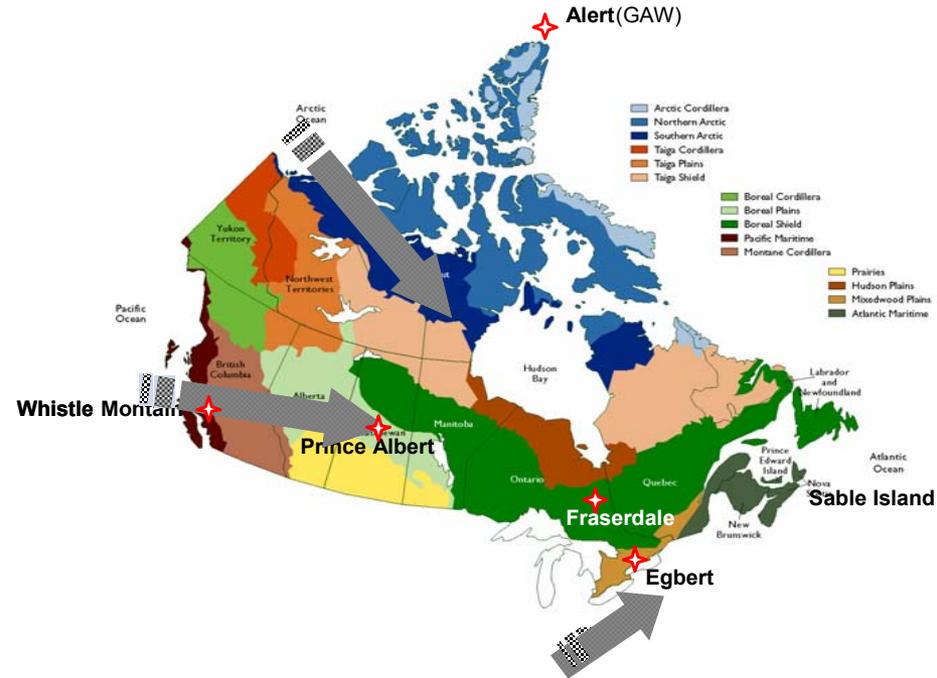
# Overall Objectives

- Assess the contribution that North American emissions make to BC levels to the northern hemispheric background as indicated by BC measurements in the Arctic.
- For the North American contribution, determine the relative contribution from transportation sources versus other sources including boreal forest fires.
- Couple regional air quality models with hemispheric models to isolate the Canadian transportation source influence on BC concentrations and spatial and temporal variation over North America and the Arctic.

# Measurement Locations

- Alert
  - longest time series
  - ongoing data analysis
- Whistler Mtn.
  - trans-Pacific
- Prince Albert and Fraserdale
  - continental background
- Egbert
  - near-urban

BC Measurements Sites over Canada(MSC)



# Atmospheric Processes

- Focus on the "aging" of fresh fine particle emissions in the regions around large urban areas
  - Mobile laboratory measurements
  - Evolution of the composition and isotopic ratio
  - Changes in hygroscopicity
  - Changes in light absorption

# Emissions

- Develop understanding how optical properties of fresh mobile source emissions correlate with chemical composition, particle size distribution, hygroscopicity.
  - Comparison of OC and BC measurement methods
  - Study different mobile source emissions (gasoline, diesel, various aftertreatment strategies)
  - Carbon isotope measurements using conventional and renewable fuels.

# Emissions and Modeling

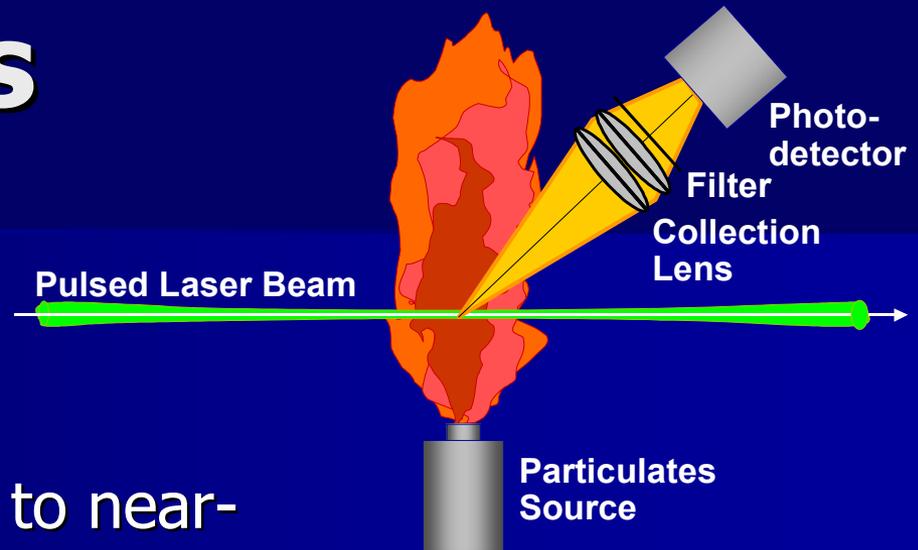
- Improving estimates of contribution from boreal forest fires and transportation in Canada
- Compilation of detailed Canadian BC inventory and merging with N.A. and N. Hemisphere emissions
- Coupling of regional air quality model (AURAMS) with global hemispheric model
  - comparison with measurements
  - analysis of source-receptor relationships
  - policy scenarios

# $^{13}\text{C}/^{12}\text{C}$ Ratio on Fine Particles

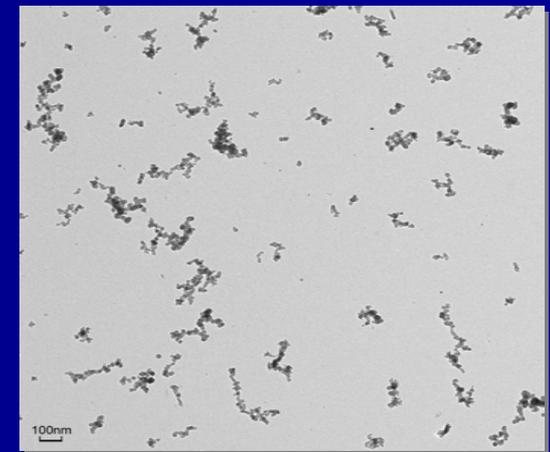
- Carbon isotope ratios vary between sources and can also fractionate further in the atmosphere.
  - spatial and temporal differences in the distribution of the isotopic composition of OC and BC are hypothesized to reflect the influence of different sources (e.g., biomass vs. fossil fuel burning).
- The measurement technique has been developed at MSC
  - future research will focus on obtaining more "source profiles", comparison of geographic areas and combining isotopic information with other data to gain insight into the importance of transportation emissions

# LII Concepts

- LII experiment:
  - pulsed laser beam
  - rapid heating of soot to near-sublimation temperatures
  - soot radiates incandescence as it cools to ambient temperature
  - incandescence signal is collected to determine soot concentration, surface area, and primary particle (spherule) size



TEM image of flame soot



# Laser-induced Incandescence (LII)

- Measures only refractory carbon
  - elemental carbon  $\approx$  dry soot  $\approx$  black carbon  $\approx$  carbon black
- Auto-Compensating LII (AC-LII)
  - absolute intensity calibration and measurement of particle temperature lead to automatic compensation for variations in experiments:
    - changes in ambient temperature, laser energy
    - condensed species – sulfates, nitrates, hydrocarbons, water
- measures ensemble statistics
- large measurement range
- good sensitivity ( $10 \mu\text{g}/\text{m}^3$ )

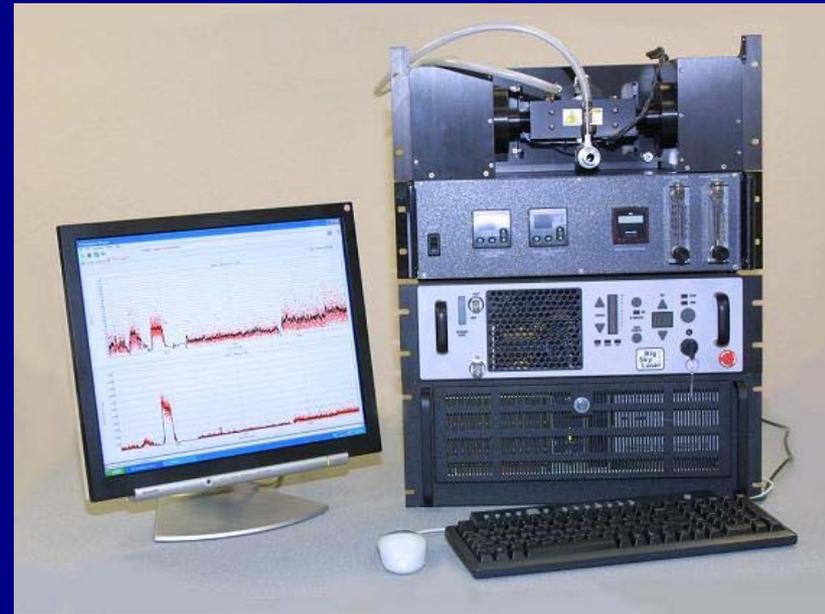


# LII for Ambient BC Measurements

- Improve sensitivity
  - target is  $0.1 \mu\text{g}/\text{m}^3$  (0.05 ppt, or 1 femtogram) detection limit
- Measure aggregate size using elastic light scattering
- Develop combined experimental theoretical methods to determine the optical and physical properties of black carbon
- Comparison to photoacoustic sensor

# LII Applications

- working high sensitivity LII instrument suitable for making measurements of ambient concentration of black carbon
- mobile platform that may be applied to on-road, non-road, marine, and aviation measurements



# Outputs - 1

- Improved data analysis methods to understand the processes involved in long-range transport of BC to the Canadian Arctic
- Measurement results of emission rates, optical properties, chemical composition of BC containing particles from selected transportation sources and biomass burning events.
- Improved inventories of BC emissions from transportation and biomass burning events to be used as model input that will improve knowledge of spatial and temporal resolution of the emissions.

# Outputs - 2

- Obtain carbon isotope ratio measurements on different BC emission sources including transportation and biomass burning and develop information and methods necessary for using these ratios in improved source apportionment work.
- Use carbon isotope measurements combined with other measurements to understand atmospheric processing of BC emissions.
- Existing models will be expanded to accurately reflect the atmospheric processes that change the BC and aerosol composition from source to regional scale air quality levels. These models can be used to take advantage of the fine resolution of BC emission inventories constructed at the local scale to produce representative averaged input for larger scale hemispheric or global models used for predicting climate change.

# Outputs - 3

- Evaluation of selected policy scenarios with the coupled regional scale/hemispherical scale model.
- Laser-induced incandescence instrument capable of measuring black carbon concentration and morphology at ambient atmospheric concentrations.
- Improved assessment of BC contribution to atmospheric warming based upon LII measurements of BC optical and physical properties, number and volume/mass concentration.

**Thank-you**

# Climate Change Plan for Canada

- Instruments for achieving the CO<sub>2</sub> emissions reductions:
  - Innovation and Technology Investments
  - Infrastructure Investments
  - Partnership Fund
  - Covenants and Emissions Trading
  - Targeted Measures

# Timeline

- Initial funding received (\$50K in 2003-04) to do preliminary work on BC in support of full proposal
- Research Proposal submitted October 1, 2004
- Funding allocations to be made in December 2004
- Program to begin in January 2005.

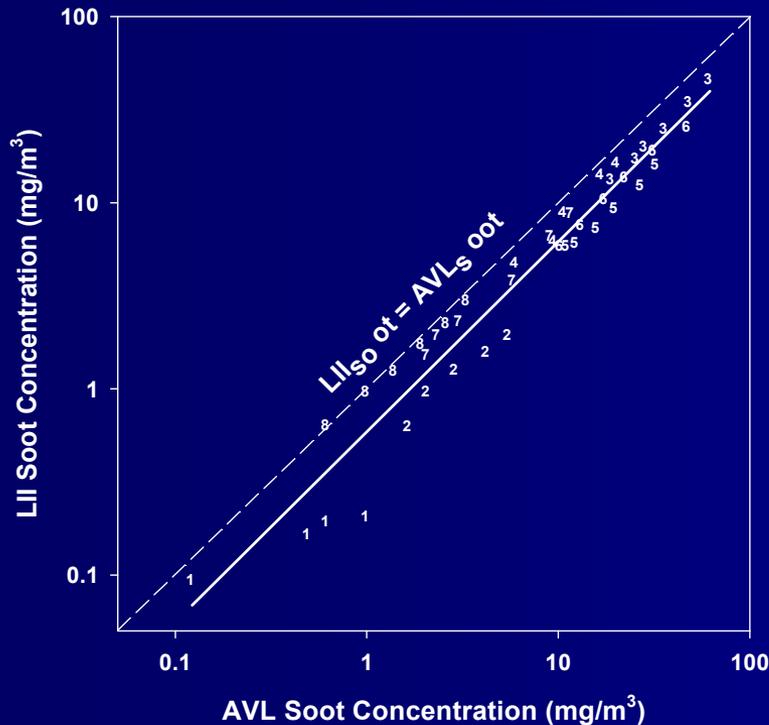
# Initial Project Results: LII

- concepts for increasing the sensitivity for LII to make black carbon measurements of concentration, active surface area, and primary particle diameter were investigated with physical modelling
  - two orders of magnitude improvement is feasible
- a technique based on light scattering for characterizing the size distribution of the black carbon aggregates was investigated
  - may provide number and size distribution

# Past Climate/BC Research

- MSC has a history of climate-related research. Examples include:
  - Global Climate Modeling
  - Inclusion of aerosol constituents in hemispheric models
  - Cloud-aerosol interactions
  - GHG and BC observations and interpretation at Alert, Fraserdale, Sable Island and other Canadian sites
  - Modeling of boreal fire emissions of OC and BC
  - Urban BC and PM measurements and health effects research

# LII: Comparison to other techniques



- LII has been demonstrated to correlate well with measures of dry soot over a wide range of concentrations:
  - gravimetric
  - AVL Smoke Meter
  - TEOM
- compared to SMPS & ELPI
- surface area correlates with I<sub>2</sub> No., NSA, STSA

# On-Road LII Measurements

- demonstrates portable in-use measurements of particulates